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Sensitivity of TOSOM Outputs to Threat Tree Variability

Daniel Hicks, Jack Reed, William Jackson
Survivability Optimization Modeling Team
Survivability Technology Center
Research, Development, and Engineering Center
US Army Tank-automotive and Armaments Command
AMSTA-TR-R, MS 263, Warren, MI 48397-5000

ABSTRACT

This paper will examine two issues of concern regarding the Threat Oriented Survivability Optimization Model (TOSOM): (1) The variability of the survivability of a baseline platform given random fluctuations of the threat tree to which the platform is subjected, and (2) The stability of the ranking of countermeasure effectiveness given random fluctuations of the threat tree.

INTRODUCTION

TOSOM is a quick, easy to use, first-order model designed to assist the decision maker in selecting affordable, integrable, and effective suites of countermeasures, armor, signature reduction, hard- and soft-kill hit avoidance, whose purpose is to optimize survivability within constraints on cost and other burdens, weight, power consumption, etcetera [1, 2].

A fundamental question to ask of any model is: How much will the outputs of the model vary as the inputs vary? This is important since the inputs are almost never known with great precision, and if the output varies greatly with small, arbitrary changes to the inputs, then the model is useless as a decision making tool. An example of an admittedly simple model will clarify what's at stake.

Example

Input to the model is a number between 0 and 1. The model then doubles this input, reducing it by 1 if it happens to exceed 1. The number obtained after repeating this doubling one hundred times is regarded as the model's output.

For instance, suppose that 1/3 is the input. One doubling gives 2/3. The second doubling gives 4/3 which is therefore reduced by 1 to 1/3. Continuing, calculation provides:

Input: 1/3
1st : 2/3
2nd : 1/3
3rd : 2/3
4th : 1/3
...
100th: 1/3,

so the model outputs 1/3 with input 1/3. Suppose now, that it is assumed that .3 is a sufficient approximation for 1/3. Calculation provides:

Input: .3
1st : .6
2nd : .2
...
100th: .8

so the output, which as was seen earlier should be identical with the input, shows that .3 is not a sufficient approximation for 1/3. Maybe a better approximation is required. But an input of .33 provides an output of .08; input .333 gives output .208; input .3333 gives output .8208. Even .33333333333333333333 as input gives output .57256866167765598208. It seems that there is no degree of approximation that is enough. Clearly, this is not a model one would want to write home about, or one upon which a decision maker should rely.

End of Example

In view of the above example, it's required to demonstrate that if the threat tree which is input to TOSOM is perturbed at random by some "small" amount, then the baseline (that is, no countermeasures) survivability of the platform under consideration is perturbed by some proportionately small amount, and that the ranking of the

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effectiveness of those countermeasures applicable to the platform generally remains the same.

In this paper, generic platforms of high baseline survivability, such as a tank, medium baseline survivability, such as an infantry fighting vehicle (IFV), and low baseline survivability, such as a truck, will be examined. Along with each of the three baseline platforms, each of five initial threat trees will be randomly perturbed at each node with five different levels of variability (±5%, ±12.5%, ±25%, ±50%, ±100%), creating thereby, five altered threat trees in addition to the initial threat tree.

Then, for each of the three platforms, it will be shown that its baseline survivability will be only very modestly affected by modest perturbations of its threat tree and that the ranking of countermeasures selected to protect that platform will likewise remain highly constant.

THE THREAT TREE

TOSOM allows threat trees with up to five branches at each node, and permits nodes to be up to five levels deep. Thus, at the extreme, TOSOM will allow threat trees with 3125 threats, though generally, TOSOM threat trees contain approximately thirty threats. For illustrative purposes, and to expound on precisely what is meant by a perturbed threat tree, an overly simple threat tree will be helpful.

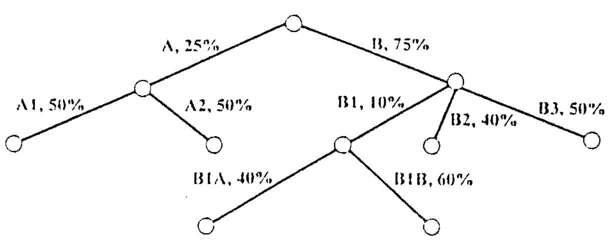

Figure 1: An Illustrative Threat Tree

The above threat tree has two nodes at level 1, five nodes at level 2, two nodes at level 3, and no nodes at levels 4 and 5. Notice also that the above tree represents six different threats (A1, A2, B1A, B1B, B2, and B3), and that the branches from each node (including the unique 0th level node) sum to 100%. The tree illustrated in Figure 1 can also be written as follows:

Level 1:	A	25%	
	B	75%	
Level 2:	A1	50%	12.5%
	A2	50%	12.5%
	B1	10%	
	B2	40%	30.0%
	B3	50%	37.5%
Level 3:	B1A	40%	3.0%
	B1B	60%	4.5%

The last column above is obtained by multiplying down the branches of the tree and provides the probability of encounter for each of the six threats.

To randomly perturb a tree by x% means the following: The occurrence of each branch, O, is replaced by, O+y, where y is a random number between -x% of O and +x% of O. Then the branches from each node are normalized. Thus, one random perturbation of 25% of the tree of Figure 1 would be:

Level 1:	A	25%	29%	27%
	B	75%	78%	73%
Level 2:	A1	50%	40%	44%
	A2	50%	50%	56%
	B1	10%	12%	11%
	B2	40%	44%	40%
	B3	50%	53%	49%
Level 3:	B1A	40%	37%	37%
	B1B	60%	62%	63%

Here, the second column of percentages are the random fluctuations of the first column of percentages, and the third column of percentages is the second such column normalized.

BASELINE SURVIVABILITY

The actual threat tree used in this study has two level 1 nodes, representing direct and indirect fire weapons; five level 2 nodes; thirteen level 3 nodes; twenty-three level 4 nodes; and two level 5 nodes; the entire threat tree represents thirty threats. Five versions of this initial threat tree are used with each version possessing a different proportion of direct to indirect fire weapons. The direct/indirect proportions for the five basic trees are 100%/0%, 75%/25%, 50%/50%, 25%/75%, and 0%/100%. Then, for each of the three considered platforms, each of the five basic threat trees is perturbed to five degrees of variability, ±5%, ±12.5%, ±25%, ±50%, ±100%. Finally, for each platform, and each initial threat tree, and each level of variability, 256 perturbed threat trees are generated in order to examine the variability of TOSOM's outputs.

The data from 256 random ±12.5% perturbations of the initial 75%/25% threat tree as applied to the high baseline survivability platform (that is, a generic tank), is:

Baseline survivability (tank, initial threat tree):	93.34%
Maximum survivability (256 perturbed trees):	93.90%
Minimum survivability (256 perturbed trees):	92.72%
Mean survivability (256 perturbed trees):	93.35%
Std deviation (256 perturbed trees):	0.19%

Here, the output is considerably more stable than the input. Why might that be? Two factors appear to be involved in this stability, one due to the nature of a perturbed threat tree, and one due to the particular platform being considered.

First, by the nature of a threat tree, a perturbed tree will increase the lethality of some threats while decreasing the lethality of others, which may thus produce only a minimal net change in lethality, and hence, in the survivability (one minus lethality) which TOSOM outputs.

Second, the platform currently under consideration, a tank, has very high initial survivability, and thus, its survivability will be only little affected by an increase or decrease in the probability of encountering any particular threat.

Because of the second reason just enumerated, the standard deviation of the corresponding case for a less survivable platform should be higher than it is in the instance above, but because of the first reason, it should still be low. This observation, in fact, will be born out by the data on the IFV and the truck. In fact, with perfect consistency, the IFV data is more variable than the tank data, but less variable than the truck data.

All twenty-five data points (5 direct/indirect fire, 5 variabilities) for the tank (each point representing 256 perturbed trees) are summarized below. It's interesting to note that the output standard deviation is approximately 1/50 of the input threat tree's variability, except in the most extreme case (±100% input variability) where the output standard deviation is approximately 1/25 of the input's variability.

Table 1: Survivability Variance, Tank

		Direct/Indirect Fire Ratio				
		100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	Baseline	94.17%	93.34%	92.52%	91.70%	90.88%
	Max	94.40%	93.53%	92.72%	91.94%	91.19%
	Min	93.97%	93.17%	92.24%	91.44%	90.53%
	Mean	94.17%	93.33%	92.53%	91.69%	90.89%
	Std Dev	0.08%	0.08%	0.08%	0.09%	0.12%
±12.5%	Baseline	94.17%	93.34%	92.52%	91.70%	90.88%
	Max	94.70%	93.90%	93.08%	92.27%	91.62%
	Min	93.54%	92.72%	91.77%	91.07%	89.83%
	Mean	94.17%	93.35%	92.50%	91.73%	90.86%
	Std Dev	0.20%	0.19%	0.21%	0.23%	0.32%
±25%	Baseline	94.17%	93.34%	92.52%	91.70%	90.88%
	Max	95.05%	94.16%	93.66%	93.10%	92.63%
	Min	92.95%	92.14%	91.17%	90.02%	88.98%
	Mean	94.18%	93.35%	92.45%	91.68%	90.87%
	Std Dev	0.43%	0.41%	0.41%	0.55%	0.69%
±50%	Baseline	94.17%	93.34%	92.52%	91.70%	90.88%
	Max	96.51%	94.83%	94.16%	93.88%	93.43%
	Min	90.44%	90.52%	89.64%	87.76%	86.30%
	Mean	94.06%	93.12%	92.26%	91.51%	91.53%
	Std	0.83%	0.83%	0.87%	1.09%	1.35%
±100%	Baseline	94.17%	93.34%	92.52%	91.70%	90.88%
	Max	97.49%	96.35%	95.44%	96.43%	96.89%
	Min	77.83%	79.16%	78.89%	73.29%	60.21%
	Mean	93.96%	92.37%	91.66%	90.48%	89.83%
	Std Dev	2.93%	2.85%	3.35%	3.82%	4.79%

There are several additional interesting observations to be made about the above table, and the two tables of data immediately following.

First, in Table 1 above, the 100%/0% baseline survivability is 94.17%, while the 0%/100% baseline survivability is 90.88%. This means that indirect fire weapons are slightly more lethal against a tank than are direct fire weapons. This observation reverses itself for both the IFV and the truck as can be seen in Tables 2 and 3 below. That is, for the IFV and the truck, direct fire weapons are a more lethal threat than indirect fire weapons, and in the case of the truck, they are dramatically more lethal.

Second, for any platform, if the 100%/0% and 0%/100% direct/indirect fire baseline survivabilities are known for that platform, then the z%/(100-z)% baseline survivability can be calculated (please see [2]), where z is any number between 0 and 100. The formula is:

z%/(100-z)% baseline survivability =
(z/100)*(100%/0% baseline survivability)
+ ((100-z)/100)*(0%/100% baseline survivability).

In the Table 2, all twenty-five data points (5 direct/indirect fire, 5 variabilities) for the IFV (each point representing 256 perturbed trees) are summarized. It's also worth noting that, as expected, the standard deviation for the IFV is higher, by about 60%, than was the standard deviation of the tank. Additionally, it can be seen that the output standard deviation is about 1/30 of the variability of the input threat tree, except in the most variable case where the standard deviation of the output is about 1/20 of the input's variability. In the Table 3, all twenty-five data points (5 direct/indirect fire, 5 variabilities) for the truck (each point representing 256 perturbed trees) are summarized.

It's worth noting that, as already mentioned, the output standard deviation for the truck is generally higher than that of both the IFV and the tank. Notice also that the truck's output variability for a given input variability is more dramatic than that of either the IFV or the tank. Additionally, it can be seen that the output standard deviation is about 1/15 of the variability of the input threat tree, except in the most extreme input case (±100%) where the standard deviation of the output is about 1/10 of the input's variability.

Table 2: Survivability Variance, IFV

		Direct/Indirect Fire Ratio				
		100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	Baseline	75.30%	78.94%	82.68%	86.22%	89.86%
	Max	75.69%	79.47%	83.09%	86.62%	90.20%
	Min	74.77%	78.37%	82.02%	85.78%	89.46%
	Mean	75.31%	78.92%	82.58%	86.22%	89.84%
	Std Dev	0.17%	0.18%	0.19%	0.15%	0.14%
±12.5%	Baseline	75.30%	78.94%	82.58%	86.22%	89.86%
	Max	76.42%	80.09%	83.69%	87.28%	90.72%
	Min	73.92%	77.77%	81.24%	85.05%	88.92%
	Mean	75.33%	78.91%	82.50%	86.20%	89.86%
	Std Dev	0.49%	0.46%	0.48%	0.39%	0.34%
±25%	Baseline	75.30%	78.94%	82.58%	86.22%	89.86%
	Max	77.77%	81.22%	85.25%	87.97%	91.62%
	Min	72.33%	76.37%	80.44%	83.95%	87.71%
	Mean	75.21%	78.96%	82.55%	86.16%	89.85%
	Std Dev	0.94%	0.91%	0.95%	0.76%	0.67%
±50%	Baseline	75.30%	78.94%	82.58%	86.22%	89.86%
	Max	79.40%	83.74%	86.60%	89.21%	92.38%
	Min	70.68%	73.66%	76.86%	81.76%	84.40%
	Mean	75.42%	79.00%	82.14%	85.80%	89.47%
	Std	1.72%	1.97%	1.90%	1.48%	1.32%
±100%	Baseline	75.30%	78.94%	82.58%	86.22%	89.86%
	Max	86.23%	91.42%	92.97%	94.05%	95.26%
	Min	50.81%	61.29%	63.93%	65.06%	66.98%
	Mean	74.24%	78.14%	81.03%	84.39%	88.25%
	Std Dev	4.90%	5.01%	4.96%	5.32%	4.72%

Table 3: Survivability Variance, Truck

		Direct/Indirect Fire Ratio				
		100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	Baseline	29.61%	48.85%	52.09%	63.33%	74.58%
	Max	30.10%	41.91%	53.25%	64.24%	74.98%
	Min	29.20%	39.97%	50.97%	62.48%	74.02%
	Mean	29.62%	40.85%	52.14%	63.36%	74.56%
	Std Dev	0.17%	0.38%	0.48%	0.38%	0.17%
±12.5%	Baseline	29.61%	40.85%	52.09%	63.33%	74.58%
	Max	30.93%	43.20%	54.67%	65.22%	75.68%
	Min	28.55%	38.79%	49.30%	61.08%	73.25%
	Mean	29.66%	40.88%	52.15%	63.33%	74.55%
	Std Dev	0.41%	0.90%	1.18%	0.90%	0.45%
±25%	Baseline	29.61%	40.85%	52.09%	63.33%	74.58%
	Max	31.82%	45.22%	58.55%	68.44%	77.21%
	Min	27.33%	35.84%	46.51%	57.72%	71.94%
	Mean	29.65%	40.62%	51.62%	63.51%	74.44%
	Std Dev	0.84%	1.94%	2.48%	1.94%	0.92%
±50%	Baseline	29.61%	40.85%	52.09%	63.33%	74.58%
	Max	35.01%	51.49%	63.99%	72.37%	78.72%
	Min	25.27%	32.17%	41.24%	52.89%	66.39%
	Mean	29.78%	41.01%	52.56%	62.86%	74.50%
	Std	1.89%	3.75%	4.80%	4.09%	2.06%
±100%	Baseline	29.61%	40.85%	52.09%	63.33%	74.58%
	Max	53.18%	75.06%	77.15%	83.47%	87.14%
	Min	16.54%	22.19%	8.69%	27.18%	38.90%
	Mean	29.88%	41.93%	51.81%	61.06%	72.33%
	Std Dev	4.79%	9.42%	11.78%	10.79%	7.41%

STABILITY OF COUNTERMEASURE SELECTION

The primary purpose of TOSOM is to provide the decision maker with the ability to determine an appropriate suite of countermeasures for the platform under consideration, and to make such a determination in a timely fashion. It is thus of considerable importance to have confidence that the countermeasures that TOSOM recommends will be stable under small, random fluctuations of the threat tree.

The methodology to instill the required level of confidence in TOSOM's countermeasure selection will begin with some description of the considered countermeasures. For the IFV, there will be seven candidate countermeasures named: CMa, CMb, ..., CMg. The countermeasures will not be described in detail. For the tank, ten countermeasures will be considered, and eight countermeasures will be considered for the truck. In each instance, only countermeasures appropriate for the platform are considered (for example, no active protection system on the truck).

Now, a matrix, with columns labeled by the countermeasures, and rows labeled by countermeasure rank is created. If all 256 perturbations of the threat tree provided the same ranking of the countermeasures as the baseline tree, then the matrix would appear as in Table 4.

Table 4: IFV 75%/25% Example Countermeasure Rankings

	CMa	CMb	CMc	CMd	CMe	CMf	CMg
1	0	256	0	0	0	0	0
2	0	0	0	0	256	0	0
3	0	0	0	256	0	0	0
4	0	0	0	0	0	256	0
5	0	0	256	0	0	0	0
6	0	0	0	0	0	0	256
7	256	0	0	0	0	0	0

Table 4 shows that for the IFV with the 75%/25% direct/indirect fire baseline threat tree, CMa is the least effective countermeasure, while CMb is the most effective countermeasure. CMe is 2nd, CMd 3rd, CMf 4th, CMc 5th, and CMg 6th.

Of course, perturbing the baseline threat tree will, most likely, not leave CMb as the most effective countermeasure in all 256 cases. What actually happens for the ±5% variability case is shown in the Table 5.

Table 5: IFV 75%/25%, ±5% Countermeasure Rankings

	CMa	CMb	CMc	CMd	CMe	CMf	CMg
1	0	256	0	0	0	0	0
2	0	0	0	7	249	0	0
3	0	0	0	249	7	0	0
4	0	0	0	0	0	256	0

5	0	0	256	0	0	0	0
6	0	0	0	0	0	0	256
7	256	0	0	0	0	0	0

Table 5 shows that, with ±5% variability on the 75%/25% direct/indirect fire threat tree, in all 256 cases CMb does, in fact, remain the most effective countermeasure. In fact, the only change from the baseline case is that countermeasures CMe and CMd, ranked 2nd and 3rd respectively, flip rank in 7 of the 256 perturbed trees. In order to measure just how close Tables 4 and 5 are, the correlation between the two Tables is calculated. In this instance it is 99.98%. Thus, the modeler, at least in this instance, can be confident that his selection of a survivability suite will be stable in the face of random, unbiased fluctuations in the probability of encountering the various threats.

The correlation data for all three platforms (tank, IFV, truck), five initial direct/indirect fire threat trees (100%/0%, 75%/25%, 50%/50%, 25%/75%, 0%/100%), and five levels of variability (±5%, ±12.5%, ±25%, ±50%, and ±100%) are summarized in Tables 6 through 8.

Table 6: Countermeasure Correlation for Tank

	Direct/Indirect Fire Ratio				
Tree Var	100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	100.00%	99.24%	99.65%	99.75%	98.60%
±12.5%	99.95%	93.77%	97.71%	94.51%	91.19%
±25%	99.04%	85.69%	95.40%	87.46%	86.91%
±50%	97.81%	73.75%	86.61%	79.25%	80.34%
±100%	93.4%	58.81%	67.18%	61.97%	73.28%

Table 6 shows that if the threat tree variability is in the ±12.5% range, then the modeler can be confident that the suite of countermeasures selected for the tank is an appropriate one.

Table 7: Countermeasure Correlation for IFV

	Direct/Indirect Fire Ratio				
Tree Var	100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	100.00%	99.98%	99.72%	100.00%	100.00%
±12.5%	100.00%	98.49%	96.25%	100.00%	99.50%
±25%	99.97%	96.73%	94.96%	99.55%	98.23%
±50%	97.19%	93.75%	91.88%	96.79%	94.05%
±100%	91.10%	78.83%	80.33%	86.22%	83.97%

Table 7 shows that if the threat tree variability is in the ±50% range, then the modeler can be confident that the suite of countermeasures selected for an IFV is an appropriate one.

When comparing Tables 6 and 7, it's seen that the countermeasure ranking for the IFV is considerably more stable than the corresponding ranking for the tank. The reason for this is that the effectiveness of the individual IFV countermeasures differ from one another by a greater amount than do those for the tank. Thus, it takes more shaking of the threat tree to disturb the ranking of the IFV's countermeasures.

Table 8: Countermeasure Correlation for Truck

	Direct/Indirect Fire Ratio				
Tree Var	100%/0%	75%/25%	50%/50%	25%/75%	0%/100%
±5%	100.00%	100.00%	99.91	99.87%	100.00%
±12.5%	99.99%	100.00%	97.85	96.87%	99.63%
±25%	99.21%	99.99%	95.92	91.03%	96.97%
±50%	96.30%	98.44%	90.7	83.35%	90.01%
±100%	86.58%	83.85%	79.58	69.96%	84.13%

Table 8 shows that if the threat tree variability is in the ±25% range, then the modeler can be confident that the suite of countermeasures selected for the truck is an appropriate one.

When comparing Tables 6, 7, and 8, it's seen that the countermeasure ranking for the truck is more stable than the corresponding ranking for the tank, but less stable than that for the IFV. However, for all three platforms, it can be seen that modest errors, on the order of ±10%, will have no effect on the selection of the most effective countermeasures.

CONCLUSION

TOSOM is a very stable model in the sense that its output will remain stable, constant, with random, unbiased variations of the input threat distribution for a wide variety of platforms.

BIBLIOGRAPHY

[1] TOSOM User's Guide, Version 1.1, June 1996, Teledyne Brown Engineering.

[2] TOSOM Anatomy with Examples, Dave Fredrick, Daniel Hicks, Jack Reed, and William Jackson, *Proceedings of the 1996 Ground Target Modeling and Validation Conference.*